RESEARCH HIGHLIGHT
Basic Energy Sciences Program
Geosciences Subprogram

Project: Laboratory and Theoretical Analyses of Transport Paths in Single Natural Fractures

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Objective of Project: To identify and understand the fundamental relationships among fracture surface roughness and the transport properties of single fractures in rock.

Background: Rock joints are ubiquitous throughout the crust. They form continuous systems, saturated with fluid, to depths in excess of 20 km. The country rock is relatively impermeable to the flow of fluids, and so the joint system often forms the network that controls the transport properties (e.g., electrical conductivity, hydraulic permeability, diffusion coefficient, and streaming potential) of the near-surface strata.

In typical situations, the transport properties of a particular rock formation cannot be measured directly and must be inferred from auxiliary field data augmented by theory. In practice, very little information about transport properties can be reported with confidence because the theory is still in rudimentary form. Particular difficulties in analysis have arisen when the fracture aperture is small, that is, when the aperture is of the same order as the roughness of the joint surfaces and portions of the joint surfaces are in contact. This is the condition that is likely to prevail in the crust except, perhaps, at very shallow depths near the surface or where the fracture walls are propped apart with debris or by excessive fluid pressure.

New Results: Direct calculation of the flow and transport properties of rock joints is not practical as a regular practice since the fracture aperture must be described in great detail and the solutions involve time consuming finite difference or finite element computations. Therefore, approximate theories and computation methods are sought for routine applications. Effective media theories, developed for and applied to various problems in physics, provide an attractive option to exact calculations. Effective media theories are simple to implement on the computer and do not require an exact description of the fracture aperture. However, contrary to prediction of standard effective media theories for this application, we find that when fracture surfaces are brought together under pressure to become nearly closed the fracture can still transmit large amounts of fluid.

Channeling of flow is the fundamental reason behind the failure of effective media theory to predict the hydraulic and electrical conductivity of rock joints. The effective media theory referred to above is predicated on the assumption that the aperture field is completely disordered; that is, the height of a point on the surface is uncorrelated with the heights of adjacent points. This assumption contradicts the description of a rough surface as a collection of peaks, summits, valleys, etc. For example, the existence of a peak, which is defined by geometric terms such as slope and curvature, requires some short-range order. This short-range order has been discarded in standard effective media theory. We have modified the standard effective media theory by introducing a simple type of non-randomness in an attempt to simulate features like topographic hills and valleys. Using this new model, we have calculated overestimates and underestimates of electrical and hydraulic conductivity as a function of the separation between the fracture surfaces. The underestimate was found to be very close to the standard effective media theory, real-space renormalization, and first-order perturbation theory results. The average of the overestimate and underestimate is a good approximation to the published values found from calculations of electrical and hydraulic conductivities for simulations of real rock joints.

Significance: The aperture distributions in natural fractures can be considered a 2-D porous medium with complex geometry. Fluid flow and transport through fractures is expected to be channeled through the high aperture regions. By knowing a few statistical properties of the fracture aperture field, but without knowing the specific location of the channels or pathways, we can study the overall flow and transport properties using this new theory. This theory might find more widespread use in physics where spatially correlated functions are important, or our derivation might provide a model for further modifications to standard effective media theories.

Publications: Walsh, J. B., S. R. Brown, and W. B. Durham, Effective media theory with spatial correlation for flow in a fracture, J. *Geophys. Res.*, 102, 22,587-22,594,1997.